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FOREST INSECT INVESTIGATIONS

ADDITIONAL OBSERVATIONS OF THE EFFECTS OF LOW TEMPERATURE UPON OVERWINTERING POPULATIONS OF DENDROCTONUS BREVICOMIS LEC.

OREGON - 1935

By

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TABLE OF CONTENTS

SUMMARY

Sub-zero weather during the first week of November, 1935, established a new early season record of -27 degrees F. in the state of Oregon. Low temperatures were recorded on the Deschutes, Fremont, and Ochoco National Forests. This gave an opportunity to continue the observations, begun in 1932, of the effects of low temperatures upon Dendroctonus brevicomis brood under field conditions.

Bark samples from 6 areas were examined during December with the aid of two CCC helpers. A total of 130.4 square feet of bark, containing 22,982 individuals in all except the egg stage, were examined. The third and fourth instar larvae, 19,885, were recorded as to their exact position in the bark.

The low temperatures of November were directed against a declining D. brevicomis population in which large larvae, third and fourth instar, predominated.

The amount of insulation over third and fourth instar larvae is shown in four graphs for as many different bark thickness groups, and is directly proportional to the bark thickness. Insulation is recognized as ~~the~~ an important factor in determining subcortical temperatures. In general, brood mortality varies inversely as the amount of insulation; the greater the insulation, the less the mortality. Brood with 1/4 inch of insulation is an unexplained exception with less mortality than brood having 1/2 inch of insulation.

Distribution of large larvae with reference to the inner bark surface is presented in graph form for 4 bark thickness groups. Approximately

90% of the overwintering third and fourth instar larvae occur within 1/4 inch of the inner bark surface. Brood mortality bears a direct relationship to the position of the brood with reference to the inner bark surface; the nearer the inner surface, the greater the mortality. The underlying causes are considered to be differences in nutritional constituents and moisture content of the bark affecting the physiological condition of the larvae.

Small larvae are less resistant to low temperatures than are large larvae; brood in trees with tight bark are less resistant to freezing than brood in trees with loose bark; brood on the north side of a tree is less cold hardy than that on the south -- all probably because of the same reason. In each case the less resistant brood exists in or near the phloem where moisture and food conditions are quite different than in the outer bark. Moisture, for example, is much greater in the phloem than in the outer bark. D. brevicomis larvae in a water saturated environment are known to experience reduced cold hardiness.

Bark texture is considered unimportant as a factor influencing the protection afforded to brood against low temperatures.

The November mortality records tend to substantiate the conclusion made in 1932-33, that minimum temperatures can be used to estimate the mortality of D. brevicomis brood to a reasonable degree of accuracy. The actual mortality came within 5% of the estimated mortality in all cases.

One contemplated control project on the Deschutes National Forest was not begun because of a reduced overwintering generation and a 50% mortality caused by low temperatures. A reduction of 20% in the Bly control unit and 40% in that near Sisters was insufficient to alter plans in these areas, where control was under way at the time the low temperatures occurred.

ADDITIONAL OBSERVATIONS OF THE EFFECTS OF LOW TEMPERATURES UPON (*Dendroctonus brevicomis* Lec.) POPULATIONS - OREGON 1935

INTRODUCTION

In the winter of 1932-33 much information was obtained concerning the effects of low temperatures upon *Dendroctonus brevicomis* brood under field conditions. The observations were reported by Miller (9), Keen and Beal (7), Beal (3), Salman (10), and Furniss (5).

Certain discrepancies developed between the findings in California and those in Oregon. These points of variance are: (1) the reaction to low temperatures of small larvae as contrasted with large larvae, and (2) the amount of mortality to brood in trees with tight bark as compared to that in trees with loose bark. Since the differences could not be reconciled, it was necessary to leave the problems unsettled until another opportunity occurred to check the conclusions.

Early in November, 1935, low temperatures over central Oregon gave the awaited opportunity to restudy the effects of low temperatures upon *D. brevicomis* brood under field conditions. A series of bark samples containing brood was obtained in late November from the area affected by the cold weather. These samples were examined during December with the aid of two CCC boys, kindly loaned for that purpose by the Forest Service.

The objects of the study were: (1) to check the conclusions reached in 1932-33; (2) to record the effects of the November, 1935, cold weather in causing mortality to *D. brevicomis* brood; (3) to secure qualitative data not heretofore obtained relative to the effects of low temperatures upon *D. brevicomis* brood under field conditions.

Minima for November, 1935:

During the last of October and the first week of November low temperatures were prevalent in central Oregon with sub-zero weather occurring from the first to the fifth of November, inclusively. Extreme cold weather in any one locality was limited to a period of one to three days. The lowest official record was taken at Lake in open desert country on the third when -27 degrees F. was reported, which established a new state record for early sub-zero temperature. Much mild weather followed the period of cold; nevertheless, the mean for the state was much below normal; only twice in 46 years, in 1896 and 1931, was the November mean lower.

The lowest temperatures centered over the open, central Oregon basin but temperatures only slightly less severe were recorded in the Deschutes National Forest. Relatively low temperatures also occurred over parts of the Ochoco and Fremont National Forests. The minimum temperatures for November, 1935, that are pertinent to this study are listed in table 1.

Minimum temperatures in the state of Washington were not as low as those in Oregon. A minimum of -8 degrees F. occurred at Lacrosse. Elsewhere the temperatures were higher with few below zero. The minima for the state are not tabulated because only one short series of bark samples was obtained which exhibited no mortality caused by freezing.

In Oregon the cold weather was marked for its considerable variation of minimum temperatures. Atmospheric conditions were calm so that temperature inversion was of common occurrence. For this reason, official weather station records were, in some cases, only approximations of the temperatures within the pine stands where the samples were taken.

Since the low temperatures were extremely unseasonable, it was considered possible that their effects upon D. brevicomis brood might be more severe than would be the case under the same temperatures later in the season. This would be true if a period of preconditioning of the brood were foreshortened.

TABLE NO. I

Minimum Temperatures for November, 1935

Weather Station		Timber Type - Environment	Elevation	Minimum Temperatures
Klamath Area:				
Klamath Falls	*	Open	4,100	+ 2°
Klamath Agency	F	Ponderosa pine	4,169	0° app.
Chiloquin	*	Lodgepole - ponderosa pine	4,200	− 15°
Crater Lake Area:				
Sand Creek	*	Lodgepole pine	4,682	− 18°
Crater Lake	*	Fir - hemlock	6,475	+ 1°
Cascade Summit	*	Lodgepole pine	4,839	0°
Lake County Area:				
Lakeview	*	Open	4,950	− 7°
Owen's Ranch	*	Ponderosa pine	4,889	− 13°
Lake	*	Open	4,300	− 27°
Silver Lake	U	Open	4,347	− 27° app.
Valley Falls	*	Open	4,300	− 19°
Pringle Falls Area:				
Pringle Falls	F	Ponderosa - lodgepole pine	4,245	− 24°
Crescent	*	Lodgepole pine	4,400	− 30° app.
Lapine	*	Lodgepole pine	4,234	− 26°
Fall River	*	Lodgepole pine	4,300	− 23°
Metolius Area:				
Bend	*	Sage, juniper, ponderosa pine	3,629	− 5°
Montgomery Ranch	*	Near ponderosa pine	1,900	− 2°
Warm Springs	*	Open grass land, canyon	1,500	− 2°
Madras	*	Open	2,241	− 12°

Table No. I continued on page 4

TABLE NO. I (Cont'd)

Minimum Temperatures for November, 1935

Weather Station		Timber Type - Environment	Elevation	Minimum Temperatures
Ochoco Area:				
Prineville	*	Open	2,867	– 15°
Ochoco R. S.	F	Ponderosa pine	3,979	0° app.
Mitchell	*	Juniper	2,766	0°
Hay Creek	*	Open canyon	2,938	– 7°
Malheur Area:				
Seneca (near)	U	Valley near timber	4,700	– 10°
Austin	*	Flat valley, open, ponderosa pine	4,200	– 14°
Harney Branch Experiment Station	*	Open	4,100	– 15°
Danner	*	Open	4,000	– 18°
Sunrise Valley	*	Open	3,700	– 16°
Umatilla Area:				
Heppner	*	Open	1,950	+ 4°
Kinzua	*	Ponderosa pine	3,450	– 7°
Ukiah	*	Open valley	3,340	– 10°
Meacham	*	Open	3,700	– 19°
Mt. Hood Area:				
Government Camp	*	Fir	3,900	+ 2°
Dufur	*	Open	1,300	+ 6°
Parkdale	*	Fir	1,700	+ 3°
		KEY:		
	*	Official Weather Bureau Station		
	F	Fire Weather Station		
	U	Unofficial Station		

Comparison of 1935 with 1932-33 Minima:

The observations in this report are essentially a comparison of the effects of the November, 1935, low temperatures with those of 1932-33; hence, a comparison of the atmospheric conditions is desirable. In the winter of 1932-33 two periods of intense cold weather occurred. The first of these, in December, 1932, was of long duration and characterized by a strong wind which blew more or less constantly, resulting in a thorough agitation of the air so that similar temperatures prevailed over wide areas. This permitted the use of standard weather station records with considerable assurance that they would apply to local areas in which bark samples were taken. The second period of cold weather, in February, 1933, was of shorter duration, more intense, but of more limited extent than that of December. This second cold weather established an all time low of -54 degrees F. for the state of Oregon.

The cold weather of November, 1935, although rather severe in a few localities, was notable chiefly for its unseasonable character by establishing a new early season record for sub-zero temperatures in Oregon. Coldest temperatures were reported in the desert area of the southeastern part of the state and in the forested basin of the upper Deschutes River. Considerable local variation in minimum temperatures occurred as a result of temperature inversion which produced lower temperatures in the natural depressions. This is illustrated by temperatures at Prineville, in the open, and Ochoco Ranger Station, in the forest, twenty-four miles apart but located in the same drainage. Prineville, approximately 1,000 feet lower than Ochoco Ranger Station, had a minimum temperature of -15 degrees

F., while that at Ochoco Ranger Station was approximately 0 degrees F.

Application of Official Weather Station Records to Forested Areas:

Since few records of winter temperatures in ponderosa pine stands are available, it is very difficult, even under the most favorable conditions, to determine the actual minimum temperatures prevalent over the varied topography of any given forested area where samples have been obtained. The problem is still further complicated when considerable local variation in temperatures is known to exist, as was the case in November, 1935. Nevertheless, until more temperature records are available in forested areas, standard weather station records must be used for what they are worth and the limitations recognized.

In ascertaining the general effects of any given series of low temperatures upon D. brevicomis brood, no great difficulty should be experienced because mortality of regional importance is caused only by widespread temperatures of -15 degrees F. or lower. Such low temperatures are readily recognized by their unusual nature, so that there is little likelihood that their importance would be overlooked. Some index of the actual application of official weather station records in the estimation of brood mortality can be obtained by a comparison of the records in 1932-33 and 1935 with the observed mortality.

If the reaction of individuals of the brood to low temperatures under field conditions is to be accurately determined, temperature records must be taken that will apply directly to the samples. This can not be done by using official weather station records unless they are definitely known to apply. Unfortunately a number of the observations in this report would

would be of much wider application if the temperatures to which the brood was subjected were known with certainty.

Areas Sampled:

Mr. Buckhorn and Mr. Jaenicke were in the field soon after the low temperatures occurred and from past experience recognized the possible effects upon D. brevicomis brood. Each independently sampled trees on the Deschutes National Forest and noted some mortality. These samples were brought to the laboratory and examined. Analysis of the samples was sufficient to show that considerable mortality had occurred in the area sampled, near Summit Stage Station and Gebhardt Well. While shaving these samples, a suitable method was developed for obtaining and recording certain desired data. That is to say, a method of sample analysis and a note form was worked out by trial and error, using the limited number of samples as a working basis.

It was necessary to secure a much longer series of samples to determine the extent and the amount of mortality and to permit of statistical analysis of various conditions pertaining to the D. brevicomis brood. Accordingly from November 18 to 26, a series of bark samples was collected chiefly from six areas in central Oregon, see map. In addition a few samples were obtained from the Mount Hood National Forest and from the Yakima Indian Reservation.

Method of Sampling:

In each of 6 areas, twenty-five or more infested trees were sampled at a point 5 feet or higher above the ground. When suitable samples were obtainable, they were taken both from the north and from the south side of the selected tree. An attempt was made to obtain samples containing large larvae in bark 1 to 1½ inches thick, because it was calculated from 1932-33

data that twenty-five samples of this kind would give a maximum error of 10 per cent. Infested trees of the desired characteristics were so difficult to find that it was necessary to take samples from whatever infested trees could be found, irrespective of the brood stage or bark thickness. All samples were brought to the Portland laboratory and analyzed during the period from December 2, 1935, to January 2, 1936.

Each sample was analyzed with two objects in view: first, to determine the number of living and dead brood; and second, to determine the exact position of each individual in the bark. Each sample containing third and fourth instar larvae was clamped in a vise and then carefully shaved along the edge grain with a very sharp draw-knife. Care was taken to hold the knife perpendicular to the inner bark surface. The measurements were made with a scale filed in 1/8 inch divisions on the back of the draw knife. Larvae occur in the bark in cells of their own construction which are often considerably larger than the bodies of the larvae, so for uniformity the measurements were taken from the extremities of these cells to the nearest bark surface, see figure 1; A, B, and C. If the larval cell touched the phloem the larva was considered to be in the phloem, see figure 1 D. Whenever the sample was of adequate size, 100 larvae were recorded with reference to the inner and outer bark surfaces.

First and second instar larvae were too small to permit the use of the same method employed with the larger larvae. It was not necessary to determine the position of the small larvae because Salman (11) had already done so with reference to the inner bark surface. Samples containing small larvae were shaved with a hunting knife and the brood noted as living or dead. No counts were made of samples containing eggs.

A total of 130.4 square feet of bark, containing 22,982 D. brevicomis brood in all except the egg stage, were examined. Of these, 19,885 third and fourth instar larvae were recorded as to their position in the bark with reference to the inner and outer bark surfaces.

Infestation Trend:

An important consideration in estimating the effects of low temperatures upon D. brevicomis population is the beetle population trend as indicated by infested timber, volume losses from year to year. These losses, when plotted against time, exhibit a rather uniform oscillation above and below a mean. Any considerable, sudden change in beetle population, as that caused by climate, becomes evident in the plotted losses when those of the year affected fall out of line with the general trend. The effects of low temperatures are not so evident when exerted in the same direction as the population trend. Comparison of the beetle-caused losses in seasons following low temperatures with the probable losses, had not the low temperatures occurred, is really an economic comparison wherein the effects of the low temperatures are averaged over two or more beetle generations. This might be called the continuing effect as contrasted with the initial effect in the first generation following population reduction.

It will be recalled that in 1932 infestation was apparently increasing. In 1933, a marked decrease occurred which was attributed primarily to the effects of the extremely low 1932-33 winter temperatures. This was especially true in Oregon where the lowest temperatures prevailed. It was notable both in Oregon and in California that, as the 1933 season progressed, beetle infestation increased rapidly.

Total seasonal losses of beetle-killed ponderosa pine during 1935 in Oregon were about 25 per cent less than in 1934. Infestation by the summer generation reached a high level with large groups being formed in many areas. Had this increase continued total seasonal losses would have been severe; however, a decided decrease occurred in the establishment of the overwintering generation. This reduction in the late seasonal generation was noted in spotting for control on the Fremont, Deschutes, and Ochoco National Forests and in the collection of bark samples for analysis. The utmost difficulty was experienced in obtaining suitable samples from 25 trees because of the scarcity of infested trees. Thus it is possible to state with definite assurance that the low temperatures in November were directed against a decreasing *D. brevicomis* population.

Overwintering Stages:

D. brevicomis brood overwinters in all except the pupal stage. New adults and parent adults comprise a very small and relatively insignificant portion of the overwintering brood. Eggs, small larvae (first and second instar) and large larvae (third and fourth instar) comprise the major portion of the overwintering brood. The relative importance of each of these is difficult to ascertain. It is believed, from data obtained in the annual cruises, that there is considerable variation from year to year.

Usually a majority of the *D. brevicomis* brood overwinters as large larvae. This was found to be the case in November, 1935, as indicated by the bark samples collected for analysis. At this time large larvae predominated but appreciable numbers of eggs and small larvae were present also. It is considered likely that the large larvae are primarily responsible for

the establishment of the first generation of the next season. There is considerable evidence that the eggs and small larvae which overwinter in the phloem, or very close thereto, experience such altered conditions of food and environmental moisture upon the resumption of activity in the spring that but few complete development into adults. It is desirable that the role of these eggs and small larvae be determined definitely.

Position of D. brevicomis Brood in Relation to the Inner Bark Surface:

Plate 1, figures 2 - 5, shows the position of D. brevicomis brood in relation to the inner bark surface by bark thickness groups. The basis for each figure is given in the plate. Large larvae only were considered because Salman (11) has determined that the first two instars occur either in the phloem or very close to it. A marked similarity exists among the figures of Plate 1 in that most of the brood occurs within the first 1/4 inch in all bark thickness groups and also because more brood occurs at 1/8 inch from the phloem than at any other point. With increased bark thickness, fewer larvae occur in the phloem. Figure 3, the graph for the 1-1/8 to 1-1/2 inch thickness group, may be considered as average for all bark thicknesses. That the position of the brood relative to the inner bark surface is of importance in relation to the effects of low temperatures upon brood mortality, will be demonstrated later.

Position of D. brevicomis Brood in Relation to the Outer Bark Surface:

Plate 2, figures 6 - 9, shows the amount of insulation over D. brevicomis brood in various bark thickness groups, using the same basis as for plate 1. As would be expected, in the thicker bark there is an increase in the amount of insulation. Figure 7, the graph for the 1-1/8 to 1-1/2 inch

bark thickness group, may be considered average for all bark thicknesses.

The amount of insulation over brood in bark of a certain thickness can be applied readily to Beal's (3) findings on the relation of air to bark temperatures of infested ponderosa pine during sub-zero weather. Figure 7, for bark 1 to 1-1/2 inches thick, may be taken as an example; then under the conditions reported by Beal with a minimum air temperature of -26 degrees F., the following modified table can be constructed to show the proportion of brood exposed to various temperatures:

TABLE NO. II

Temperatures to Which Overwintering D. brevicomis Brood (Third and Fourth Instar Larvae) Are Subjected in Bark 1 to 1½ Inches Thick, With an Air Temperature of -26°

Modified from Beal (3)

Amount of Insulation	Per Cent of Total Brood	Air Temperature	Spread Between Air and Bark Temperatures	Temperatures To Which Larvae Are Subjected	Lag of Bark Temperature Behind Air Temperature
½" or less	51.0	- 26°	8°	- 18°	1 hour
5/8 - 1"	44.3	- 26°	18° to 21°	- 5° to - 8°	1 hour
1-1/8 - 1½"	4.7	- 26°	22° to 27°	+ 1° to - 4°	2 hours

Similar tables may be constructed for the other bark thickness groups. These would merely serve to emphasize the fact that a certain small proportion of D. brevicomis brood exists under conditions of insulation that are sufficient to insure the continuation of the species within its native habitat. Insulation as a factor in brood mortality will be discussed later.

Brood Mortality by Areas:

The general effects of the low temperatures upon *D. brevicomis* brood, as shown by the samples from six areas, are listed in tables 3 to 8. Note that in area A (table 1) and area F (table 6), with minimum temperatures of approximately 0 degrees F., little mortality resulted. In areas B, C, D, and E (tables 2 - 5), in which sub-zero temperatures were prevalent, considerable mortality occurred and was directly proportional to the degree of coldness; i. e., the lower the temperature, the greater the amount of mortality to *D. brevicomis* brood. From these tables it may be concluded that the maximum mortality, 40% to 60%, occurred upon the Deschutes National Forest and that appreciable kill, 20% to 30%, occurred in the Fremont National Forest. Probably temperatures elsewhere in the pine stands of the state were not sufficiently low to cause reduction of brood. Samples from the Mount Hood National Forest and the Yakima Indian Reservation, where temperatures did not fall below zero, yielded approximately 5% mortality or within the range of mortality to overwintering brood caused by factors other than low temperatures.

Brood Mortality

Western Pine Beetle in Ponderosa Pine

Oregon Examinations 1935

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TABLE NO. 3

SOUTHWESTERN KLAMATH COUNTY - AREA "A"

Jenny Creek - T 40 S; R 4 E; Sec. 34 Elevation 3,500'

Round Lake - T 39 S; R 8 E; Sec. 5 Elevation 4,400'

Samples from 25 trees, north and south sides, 5' to 10' above ground.

Collected November 19-20, 1935, by Buckhorn and Furniss.

Examined December 2, 1935 - January 2, 1936, by Buckhorn and Furniss.

Minimum temperature November 3, 1935 + 2° F., approximate

Bark Thickness in Inches	No. Samples	No. Sq. Ft.	Western Pine Beetle Brood			Total Larvae per Sq. Ft.	Percent Killed
			Living	Dead	Total		
5/8 - 1	7	4.6	451	36	487	106	7.4
1-1/8 - 1½	21	10.8	1632	102	1734	161	5.9
1-5/8 - 2	17	6.6	1492	113	1605	243	7.0
2-1/8 - over	4	1.9	468	19	487	256	3.9
Total or Average	49	23.9	4043	270	4313	180	6.3

Weighted Average -------------------------------- 8.7%

TABLE NO. 4

FREMONT NATIONAL FOREST - AREA "B"

Deming Creek Control Area - T 36 S; R 15 E; Sec. 25 Elevation 5,500'

Samples from 25 trees, north and south sides, 5' to 10' above ground.

Collected November 20-21, 1935, by Buckhorn and Furniss.

Examined December 2, 1935 - January 2, 1936, by Buckhorn and Furniss.

Minimum temperature November 3, 1935 - 13° F.

Bark Thickness in Inches	No. Samples	No. Sq. Ft.	Western Pine Beetle Brood			Total Larvae per Sq. Ft.	Percent Killed
			Living	Dead	Total		
5/8 - 1	6	3.9	185	181	366	94	49.5
1-1/8 - 1½	25	15.4	1593	467	2060	134	22.7
1-5/8 - 2	9	4.5	671	71	742	165	9.6
2-1/8 - over	4	2.1	353	34	387	184	8.8
Total or Average	44	25.9	2802	753	3555	137	21.2

Weighted Average ---------- ----------------------- 27.0%

TABLE NO. 5

DESCHUTES NATIONAL FOREST - AREA "C"

Summit Stage Station - T 25 S; R 11 E; Sec. 11 Elevation 4,800'

Gebhardt Well - T 25 S; R 12 E; Sec. 25 Elevation 4,800'

Samples from 25 trees, north and south sides, 5' to 10' above ground.

Collected November 22, 1935, by Buckhorn and Furniss.

Examined December 2, 1935 - January 2, 1936, by Buckhorn and Furniss.

Minimum temperature November 3, 1935, -20° F., approximate.

Bark Thickness in Inches	No. Samples	No. Sq. Ft.	Western Pine Beetle Brood			Total Larvae per Sq. Ft.	Percent Killed
			Living	Dead	Total		
5/8 - 1	8	3.1	222	568	790	255	71.9
1-1/8 - 1½	25	10.4	1174	922	2096	202	44.0
1-5/8 - 2	9	2.6	550	312	862	332	36.2
2-1/8 - over	--	--	--	--	--	--	--
Total or Average	42	16.1	1946	1802	3748	233	48.1

Weighted Average -------------------------- 57.3%

TABLE NO. 6

DESCHUTES NATIONAL FOREST - AREA "D"

Watkins Butte - T 22 S; R 16 E; Elevation 5,000'

Samples from 27 trees, north and south sides, 5' to 10' above ground.

Collected November 23-24, 1935, by Buckhorn and Furniss.

Examined December 2, 1935 - January 2, 1936, by Buckhorn and Furniss.

Minimum temperature November 3, 1935 -20° F., approximate.

Bark Thickness in Inches	No. Samples	No. Sq. Ft.	Western Pine Beetle Brood			Total Larvae per Sq. Ft.	Percent Killed
			Living	Dead	Total		
5/8 - 1	3	1.4	70	174	244	174	71.3
1-1/8 - 1½	21	10.0	1321	716	2037	204	35.1
1-5/8 - 2	12	4.2	810	465	1275	304	36.5
2-1/8 - over	6	2.6	737	258	995	383	25.9
Total or Average	42	18.2	2938	1613	4551	250	35.4

Weighted Average ------------------------ 50.9%

TABLE NO. 7

DESCHUTES NATIONAL FOREST - AREA "E"

Metolius Control Area - T 14 S; R 10 E   Elevation 3,200'

Samples from 25 trees, north and south sides, 5' to 10' above ground.

Collected November 24, 1935 by Buckhorn and Furniss.

Examined December 2, 1935 - January 2, 1936, by Buckhorn and Furniss.

Minimum temperature November 3, 1935 -15° F., approximate.

Bark Thickness in Inches	No. Samples	No. Sq. Ft.	Western Pine Beetle Brood			Total Larvae per Sq. Ft.	Percent Killed
			Living	Dead	Total		
5/8 - 1	15	8.5	554	662	1216	143	54.4
1-1/8 - 1½	20	13.0	1181	461	1642	126	28.1
1-5/8 - 2	2	.4	129	71	200	500	35.5
2-1/8 - over	4	1.7	538	62	600	353	10.3
Total or Average	41	23.6	2402	1256	3658	155	34.3

Weighted Average ------------------------------ 40.2%

TABLE NO. 8

OCHOCO NATIONAL FOREST - AREA "F"

Gerow Butte - T 15 S; R 19 E; Sec. 17 & 18 Elevation 4,800'

Samples from 25 trees, north and south sides, 5' to 10' above ground.

Collected November 25, 1935, by Buckhorn and Furniss.

Examined December 2, 1935 - January 2, 1936, by Buckhorn and Furniss.

Minimum temperature November 3, 1935, 0° F., approximate.

Bark Thickness in Inches	No. Samples	No. Sq. Ft.	Western Pine Beetle Brood			Total Larvae per Sq. Ft.	Percent Killed
			Living	Dead	Total		
5/8 - 1	3	2.1	196	13	209	100	6.2
1-1/8 - 1½	14	10.1	1092	117	1209	120	9.7
1-5/8 - 2	15	9.1	1200	94	1294	142	7.3
2-1/8 - over	3	1.4	400	45	445	318	10.1
Total or Average	35	22.7	2888	269	3157	139	8.5

Weighted Average ----------------------------------- 12.1%

Brood Mortality in Relation to the Amount of Insulation:

It has been conclusively shown that bark thickness is a very important factor in determining the temperatures to which *D. brevicomis* brood will be subjected at a given air temperature. Miller (9), Keen and Beal (7), Salman (10), and Furniss (5) concluded that the amount of mortality to brood from freezing is inversely proportional to the thickness of the bark in which the brood exists; i. e., the thicker the bark the less the mortality. All average figures gave this result; however, two discrepancies needed explaining. These were: (1) individual variation between similar larvae existing under apparently identical conditions, and (2) the fact that no well defined mean could be found to exist in the samples.

To further test the effect of insulation upon *D. brevicomis* mortality from freezing, the amount of mortality was recorded among brood with different degrees of insulation. These data are shown in Plate 3. Figure 10 shows the amount of mortality for third and fourth instar larvae in samples from four areas in which appreciable mortality occurred. In this figure, position of the brood relative to the inner bark surface is not taken into account. Figure 11 illustrates the same thing but only those larvae 1/8 inch from the phloem were recorded. Larvae 1/8 inch from the phloem were chosen to insure the largest possible sample.

Brood with the least amount of insulation, 1/4 inch, falls decidedly and consistently out of line indicating, apparently, that some factor other than amount of insulation is effective in reducing amount of kill, either by being more or less effective than elsewhere. In general, with insulation greater than 1/4 inch, increasing insulation results in a decreased amount

of mortality. No ready explanation occurs to account for the unexpectedly low mortality to brood with but 1/4 inch of insulation. Seemingly the one distinguishing character of this portion of the brood is its tendency to alignment along the bark crevices, but in what manner this might reduce brood mortality is not known.

Brood Mortality in Relation to Proximity to the Inner Bark Surface:

The relation between nearness of brood to the inner bark surface and the amount of mortality caused by low temperatures is shown in Plate 4, using the same basis as for Plate 3. Figure 12 shows the amount of mortality to large larvae at 1/8 inch intervals from the inner bark surface irrespective of the amount of insulation. A straight line relationship is evident in this graph, in that brood mortality decreases with increased distance from the inner bark surface. Figure 13 illustrates the same point. Only those larvae with 1/2 inch of insulation are included. It is believed that in breaking down the data for figure 13 insufficient cases were available; however, the general trend is still quite in evidence.

It is recognized that the state of being near or far from the inner bark surface is not of itself a factor influencing the amount of D. brevicomis mortality. Since there is a difference in the amount of mortality, depending upon position of the brood in the bark and acting independent of insulation, there must be some factor or factors that cause this difference. Differences in moisture content and kind of food in outer and inner bark are considered to be the more important of these factors. No experimental evidence is advanced to show how they act.

Miller (8) and Beal (1), (4), have shown that environmental moisture plays an important role in determining the resistance of Dendroctonus broods

to low temperatures. Miller found that _D. brevicomis_ larvae in saturated bark succomb to temperatures 10 degrees higher than do larvae from normal bark. Beal, working with _D. frontalis_, noted that larvae in the phloem region suffer higher mortality from freezing than do those larvae in the outer bark. He attributed this to the relatively higher moisture content in the inner bark. The phloem of southern pine was found to contain over 200% moisture and the outer bark only about 30% on a dry weight basis.

The relationship between the moisture content of the phloem and the outer bark of ponderosa pine should not be materially different from that of southern pine. Beal (2) has shown that the phloem moisture content of green ponderosa pine ranges from 163% to 214%, which approximates that of southern pine. It is apparent that moisture content of the bark must be in equilibrium with that of the air, so we may expect to find that ponderosa pine bark is progressively drier as the outer surface is approached. From this it may be concluded that the nearer the brood occurs to the inner bark surface, the greater will be the environmental moisture. Since moisture has been shown to be an important factor influencing brood resistance to low temperatures, it is not surprising to find that those larvae living closest to the inner bark surface suffer greatest mortality, see Plate 4.

Those larvae living in the phloem have the greatest amount of insulation, yet the mortality of this group is decidedly higher than that of the larvae living farther out in the bark but with less insulation. Therefore the larvae in the phloem must succumb to higher temperatures than those in the outer bark for it has already been fully demonstrated that the amount of insulation is an important factor in determining the temperatures to which the larvae will be subjected. It is interesting to note, Plate 1,

that in thick bark the larvae tend to occur in the phloem much less frequently than in thin bark, which might partially account for the lower mortality to brood in the thick bark.

During the examination of the samples, it was recognized that the larvae tend to be distributed in the bark in two characteristic patterns. In one type the brood is concentrated in or very close to the phloem. Brood mortality is high in samples of this kind. In the second type the brood occurs in scattered fashion, chiefly well removed from the phloem. Mortality is low in samples of this kind. Insufficient samples were available for analysis of these tendencies; however, Plate 5, figures 14 and 15, serve to illustrate what is meant. The diagrams are made up in the same manner as the forms upon which the data was taken. Both bark samples were from the same area, were of the same bark thickness, and contained larvae of the same instar. The difference in the relative amount of mortality between these two types of brood occurrence is illustrated in the diagrams, 12% in figure 14, and 80% in figure 15.

Cerambycid work, resulting in a reduction of the D. brevicomis brood and decreased moisture content of the bark, was observed to be associated with relatively lower mortality than in samples in which no cerambycid work was present. Considerable variation existed among the samples which were insufficient to permit statistical analysis of the effect of cerambycid work (drying effect) upon brood mortality.

Jeffrey (6) found that food in the form of sugars is more abundant in the phloem than in the outer bark. It is altogether likely that the physiological condition of the larvae would be quite different when the

larvae feed upon different types of food, as in outer and inner bark. A corresponding difference in their reaction to low temperatures might also be expected. This point is discussed further under the effect of larval size upon amount of mortality.

Mortality in Relation to the Size of the Larvae:

In 1932-33, investigations in Oregon pointed definitely to the conclusion that small larvae are less resistant to low temperatures than are large larvae. Observations during the same winter in California indicated the reverse to be the case, although subsequent examinations showed that practically no brood developed from trees containing small overwintering larvae. Logicially enough, perhaps, the present study, made in Oregon, substantiates the earlier observations in the same area.

Larval size, like nearness to the inner bark, probably is not of itself a factor influencing the amount of brood mortality. That there may be, and probably are, physiological differences between small and large larvae that cause them to react differently to low temperatures, is undenied. We may look, however, to some factor such as environmental moisture or kind of food to account for the physiological differences. Here again we arrive at a consideration of the position of the larvae in the bark. It is immediately evident that the small larvae are in the phloem, or very close to it, while most of the large larvae are in the outer corky bark. Proximity to the inner bark surface has been shown to increase the amount of brood mortality, so it is not surprising to find that mortality at a given temperature is greater among small larvae than among large larvae. Small larvae are not subjected to temperatures quite as low as are large larvae, because of an increased amount of insulation. This increased insulation

over small larvae, to all practical purposes, amounts to about 1/4 inch (Plate 1), which would make a temperature difference of approximately 4 degrees F. (Table 2).

Table 9 gives a comparison of the percent of mortality in first and second, third, and fourth instar larvae as determined by an analysis of samples from 6 areas. In general, the amount of mortality decreases with increased larval size. Fourth instar larvae are shown to be decidedly more resistant than either of the other groups. Third instar larvae appear to be somewhat more resistant than first and second instar larvae. In this connection, it should be kept in mind that most of the third instar larvae were probably considered as small larvae in 1932-33.

Examination of the samples indicated that first and second instar larvae nearly all perished or nearly all survived the low temperatures -- depending upon conditions in the tree from which the samples happened to be taken. This is logical because the very small larvae exist under nearly identical environmental conditions, except for amount of insulation. Consequently the range of temperatures fatal to small larvae is probably quite limited.

For some time it has been recognized that there is runting of certain larvae probably caused by adverse conditions of indeterminate nature within the bark. A number of runted fourth instar larvae are probably included in the third instar and it has already been noted that mortality in this group is higher than that of the fourth instar. Furthermore, in shaving the samples it was evident time and again that samples containing larvae of small size but undoubtedly in the fourth instar would suffer higher mortality than those individuals of larger size in other samples.

This tendency was previously observed in laboratory studies at Berkeley.

Bark tightness is dependent very largely upon the degree of brood development; in general, the younger the brood, the tighter the bark. Since trees with tight bark contain the younger brood stages, it follows that brood mortality in these trees is higher than in trees with loose bark.

TABLE NO. 9

PER CENT OF MORTALITY TO D. BREVICOMIS LARVAE BY INSTARS

Area	First and Second Instars	Third Instar	Fourth Instar
A	22.3%	9.9%	2.6%
B	25.0%	30.9%	18.0%
C	51.2%	63.7%	41.4%
D	57.0%	47.7%	25.3%
E	97.2%	54.5%	25.5%
F	23.3%	23.0%	4.6%

Brood Mortality in Relation to Bark Texture:

It was noted in 1932 that there is an observed difference in brood mortality in bark of different character; i. e., spongy bark contrasted with flinty bark. The difference in degree of insulation between the two types of bark has been stressed. Mr. H. C. Dickinson in correspondence has pointed out that the diffusivities of wood, cork, and ponderosa pine bark are approximately the same. He also states that in variable heat flow, the protection afforded varies inversely with the diffusivity rather than conductivity.

Hence we may conclude that if three substances such as wood, cork, and ponderosa pine bark do not vary significantly among themselves as to diffusivity, there is little probability that various samples of one, ponderosa pine bark, will do so. Therefore we may conclude that samples of ponderosa pine bark exhibiting the range of differences in texture will all provide about the same degree of insulation against low temperatures.

It seems altogether likely that the visible differences in bark character, for example, in different tree classes, reflect certain differences of moisture content and available food for bark beetle development. These factors would be of importance upon the physiological resistance of the individual larvae to low temperatures which would be reflected in different degrees of mortality in different trees. These factors are difficult, if not impossible, to recognize in extensive field examinations and could best be studies under controlled laboratory conditions.

Mortality in Relation to the North and South Exposure on the Tree:

Keen and Beal (7) and Salman (10) have shown that larvae on the north side of a tree suffer higher mortality than those on the south side. Table 10 illustrates that the same conclusion applies to the present study. This is considered to further strengthen the theory that mortality is greater among the small larvae, because in the overwintering generation there is a definite tendency for the larvae on the north side to be less advanced than those on the south, this despite the fact that the bark on the north side is appreciably thicker on the average than that on the south, Keen and Beal (7).

TABLE NO. 10

A COMPARISON OF THE MORTALITY OF D. BREVICOMIS BROOD (CHIEFLY LARVAE) ON THE NORTH AND SOUTH SIDES OF A TREE

Area	Average Mortality North Side & South Side	Average Mortality North Side	Average Mortality South Side	Number of Cases in Which Mortality on the North Exceeded That on the South*	Number of Cases in Which Mortality on the South Exceeded That on the North*
B	21.2%	23.3%	17.8%	14	5
C	48.1%	53.9%	41.5%	13	3
D	35.4%	37.4%	32.1%	10	5
E	34.3%	34.3%	34.4%	10	4

* Samples were obtained from 25 trees in each area, but samples were not obtained from both the north and south sides in all cases.

Brood Mortality in Relation to Slope and Exposure:

In 1932-33 no marked differences could be noted on various slopes and exposures because of the thorough mixing of the air by the strong wind. Under quiet atmospheric conditions such as those of November, 1935, it would be expected that some temperature differences would exist as a result of temperature inversion. The importance of these differences would depend on the degree of difference. Since no records of local variations in temperatures were available, no efforts were made to determine the importance of slope and exposure. It is believed, however, that when temperatures are sufficiently low to be a factor in the control of D. brevicomis brood, the relatively small local differences caused by slope and exposure would not be of much general importance. To determine the effect of local topographic features upon minimum temperatures would necessitate taking a series of temperatures under the various conditions. This was not done in the present series of observations.

Determination of Brood Mortality from Weather Records:

In 1932-33, Keen and Beal (7) worked out a curve to show the amount of mortality that might be expected to D. brevicomis brood when given minimum air temperatures are reached. Some objections to the method were advanced because it was considered that the weather records, that were used, could not reasonably be expected to apply to the forested areas. The observations made in 1935 tend to confirm the conclusions of Keen and Beal.

The actual mortalities during November, 1935, in 6 areas, together with the minimum air temperatures, in so far as they could be determined, have been plotted to show their relationship to the extimated mortalities for the same temperatures, see figure 16. It is evident from this comparison

that the actual mortalities approximate the estimated mortalities very closely. In no case is there a difference of more than 5%.

This would indicate that certain air temperatures result in a fairly predictable amount of brood mortality. The accuracy depends entirely upon how closely the weather records apply to the area in which the beetles exist. There are records in parts of Oregon that apply fairly well to wide spread cold weather, but when extreme variations exist the estimate may be considerably affected. It is believed that no difficulty will be experienced in recognizing when mortality of regional importance occurs, because of the unusual nature of the temperatures that are necessary to produce this effect.

Effect of 1935 Mortality upon Control Projects:

Control projects were closed both in Oregon and California in the winter of 1932-33 as a result of the *D. brevicomis* brood mortality caused by low temperatures. At that time a reduction of 50% or more was considered necessary to influence control operations.

In November, 1935, a reduction of 50% occurred in one area near Summit Stage Station and Gebhardt Well on the Deschutes National Forest. Control was contemplated in this vicinity but through a combination of reduced infestation by the overwintering generation and the effects of the low temperatures, the project was cancelled. Elsewhere brood reduction by low temperatures was less than 50%. Two control projects were in progress at the time when the low temperatures occurred. Both were completed, one at Bly with about 20% mortality, and one near Sisters with approximately 40% reduction from freezing.

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(4) Beal, J. A. 1933 Temperature Extremes As a Factor in the Ecology of the Southern Pine Beetle. Journal of Forestry 31: 329-336.

(5) Furniss, R. L. 1934 Additional Observations on the 1932-33 Mortality of Forest Insects Due to Freezing - Northeastern California. Unpublished report.

(6) Jeffrey, R. N. 1930 The Concentration of Certain Sugars in the Bark of the Western Yellow Pine As Related to Western Pine Beetle Attraction. Unpublished report.

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(8) Miller, J. M. 1931 High and Low Lethal Temperatures for the Western Pine Beetle. Journal of Agricultural Research 43: 303-321.

(9) Miller, J. M. 1933 A Record of Winter Kill of Western Pine Beetle in California, 1932. Journal of Forestry 31: 443-446.

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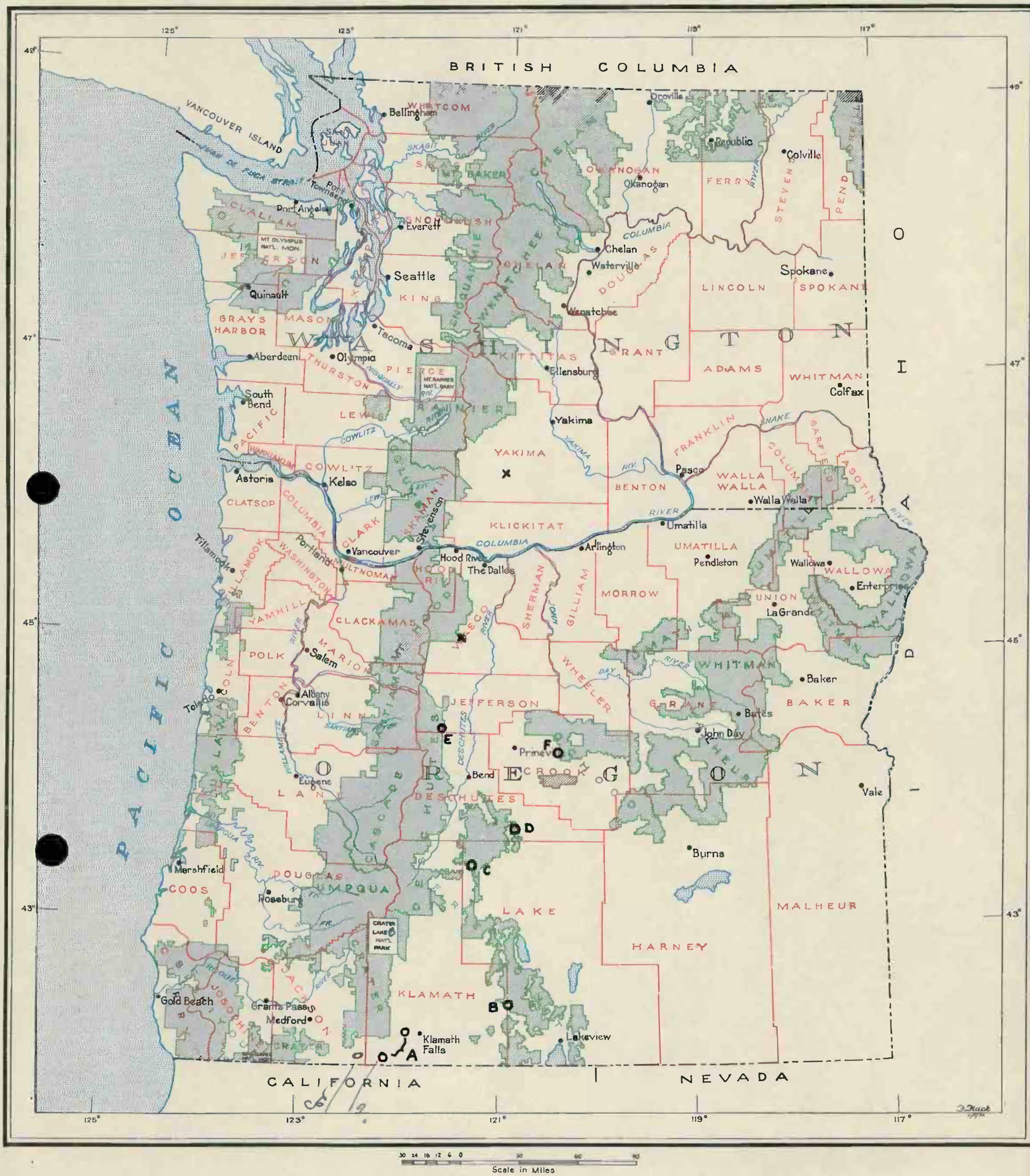


LEGEND

State Lines

National Forests

County boundaries

PACIFIC NORTHWEST FOREST EXPERIMENT STATION

LEGEND: ~~Project~~ O – LOCALITIES REPRESENTED BY BARK EXAMINATIONS FROM 25 OR MORE TREES.

X – LOCALITIES REPRESENTED BY BUT FEW BARK EXAMINATIONS.

FIGURE 1

CROSS SECTION OF PONDEROSA PINE BARK ILLUSTRATING MEASUREMENTS TO DETERMINE LARVAL POSITION

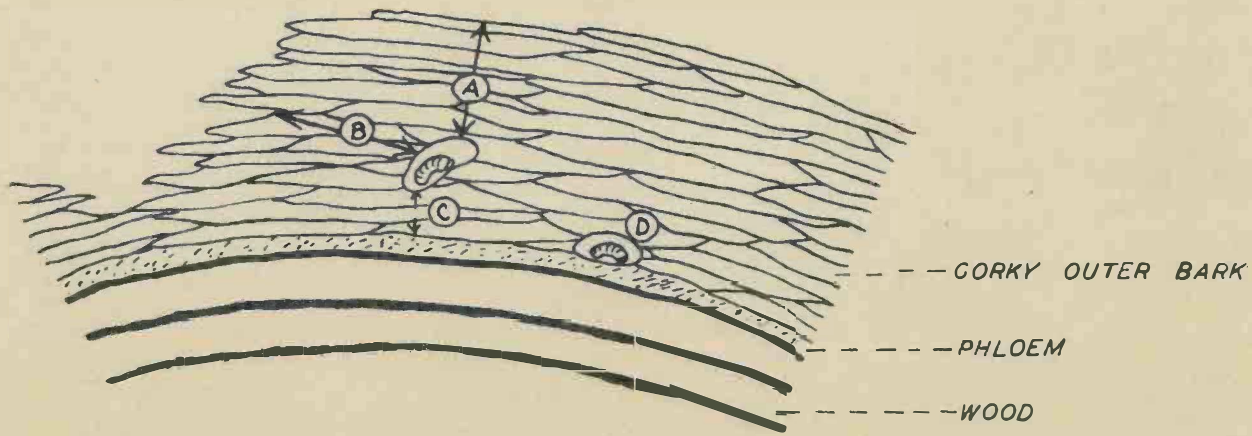


PLATE I

POSITION OF DENDROCTONUS BREVICOMIS BROOD IN RELATION TO INNER BARK SURFACE

THIRD AND FOURTH INSTAR LARVAE

Figure 2

5/8" - 1" Bark Thickness Group
(37 samples)

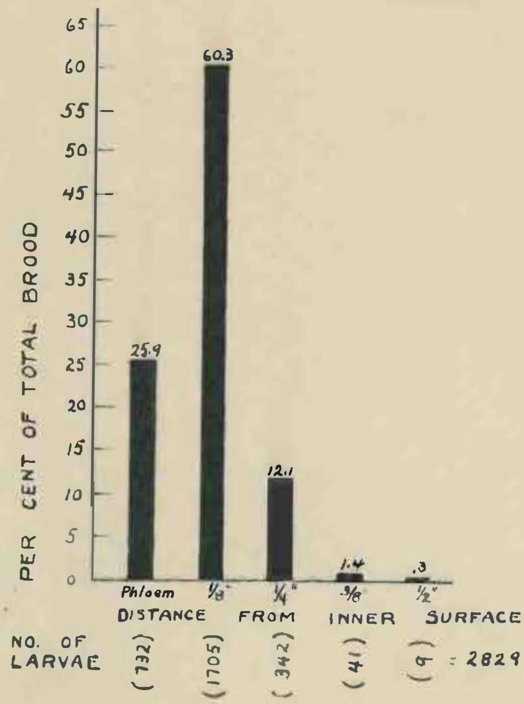


Figure 4

1 5/8" - 2" Bark Thickness Group
(52 samples)

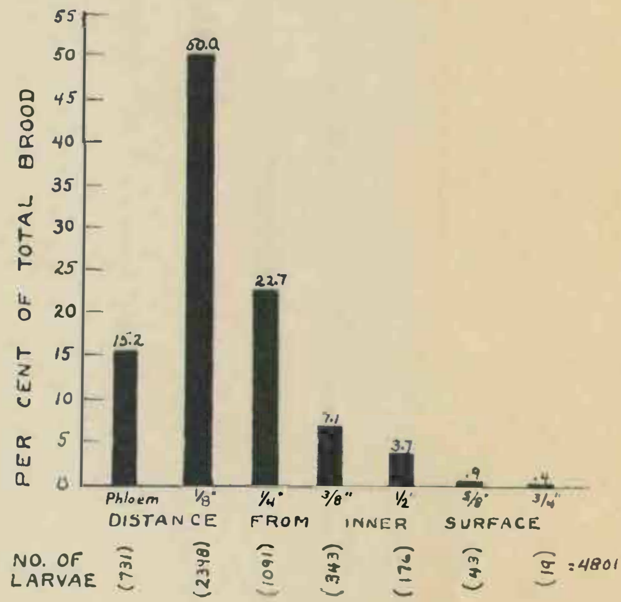


Figure 3

1 1/8" - 1 1/2" Bark Thickness Group
(113 samples)

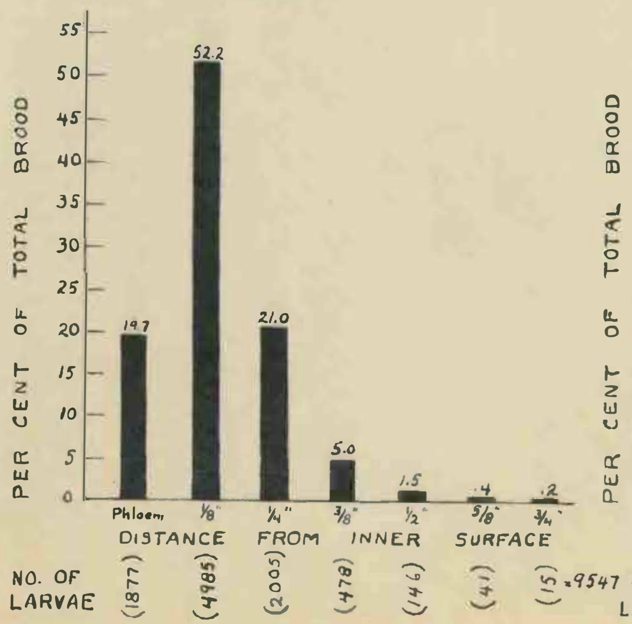


Figure 5

2 1/8" - over Bark Thickness Group
(20 samples)

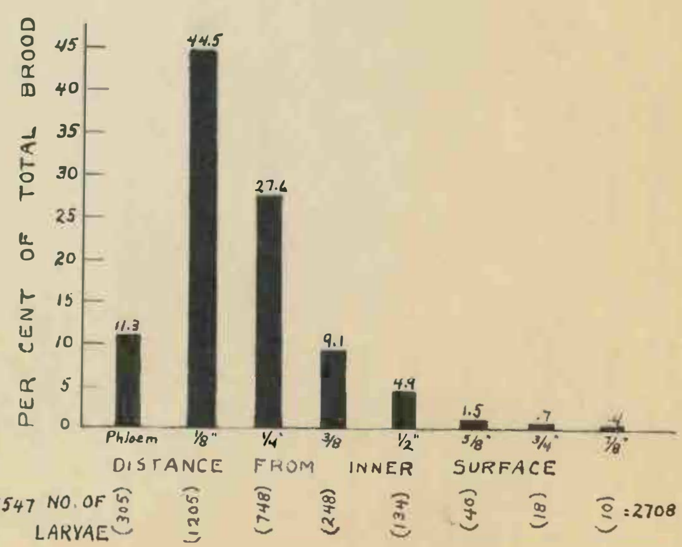


PLATE - 2

AMOUNT OF INSULATION OVER DENDROCTONUS BREVICOMIS BROOD IN WINTER

THIRD AND FOURTH INSTAR LARVAE

Figure 6

5/8 - 1" Bark Thickness Group
(37 samples)

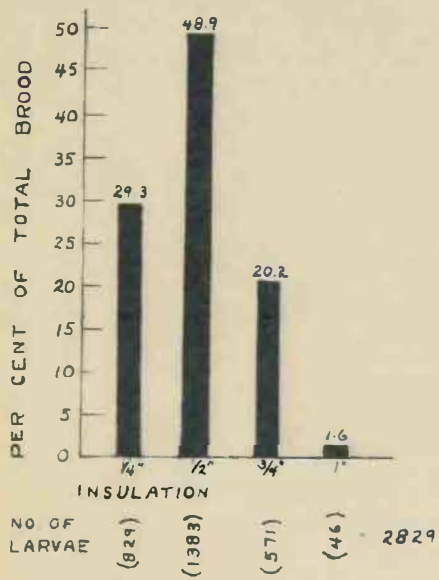


Figure 8

1 5/8" - 2" Bark Thickness Group
(52 samples)

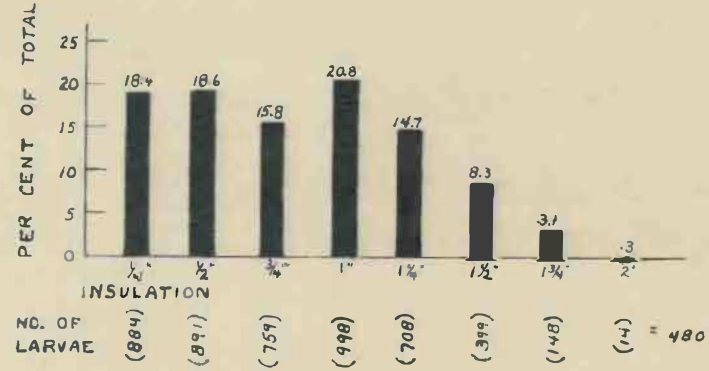


Figure 7

1 1/8" - 1 1/2" Bark Thickness Group
(113 samples)

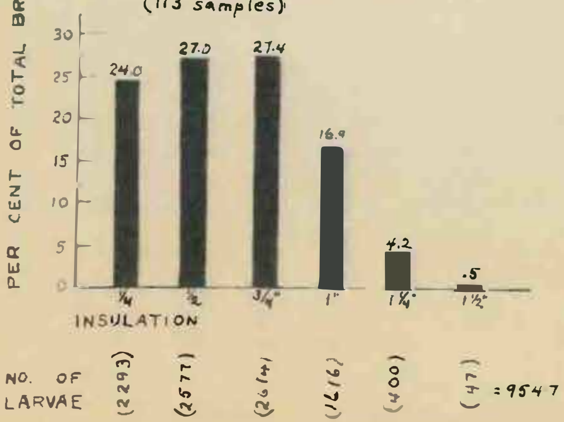


Figure 9

2 1/8 - over Bark Thickness Group
(20 samples)

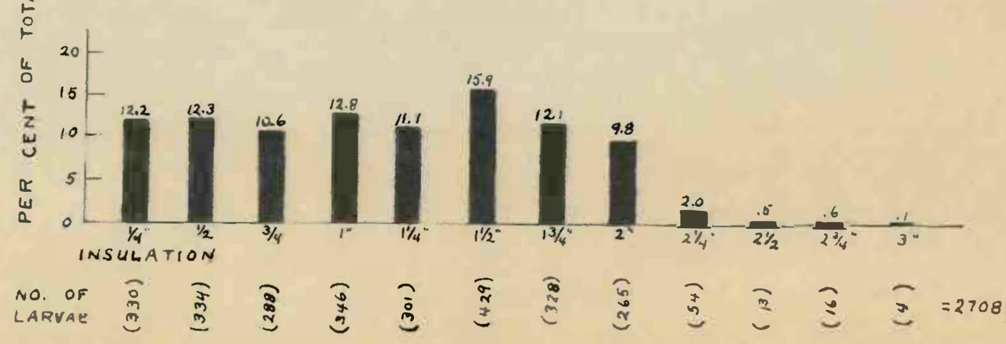


PLATE - 3

RELATIONSHIP BETWEEN MORTALITY OF D. BREVICOMIS AND THE AMOUNT OF INSULATION

FIGURE - 10

MORTALITY TO ALL THIRD AND FOURTH INSTAR LARVAE

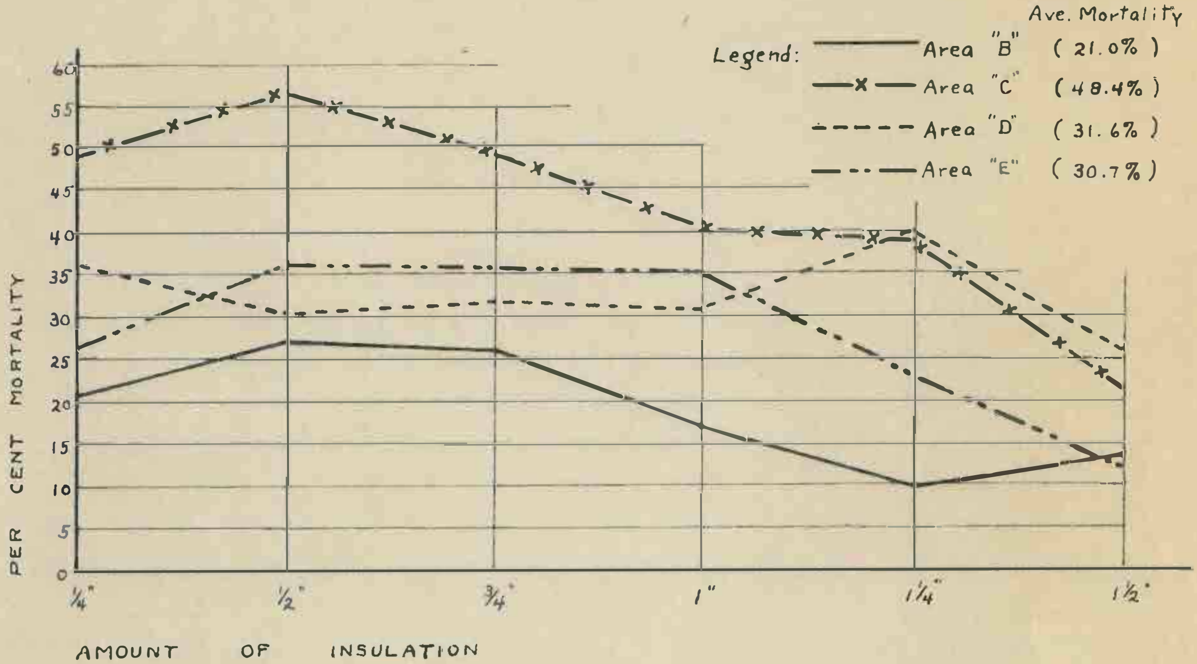


FIGURE - 11

MORTALITY TO THIRD AND FOURTH INSTAR LARVAE
1/8 INCH FROM INNER BARK SURFACE

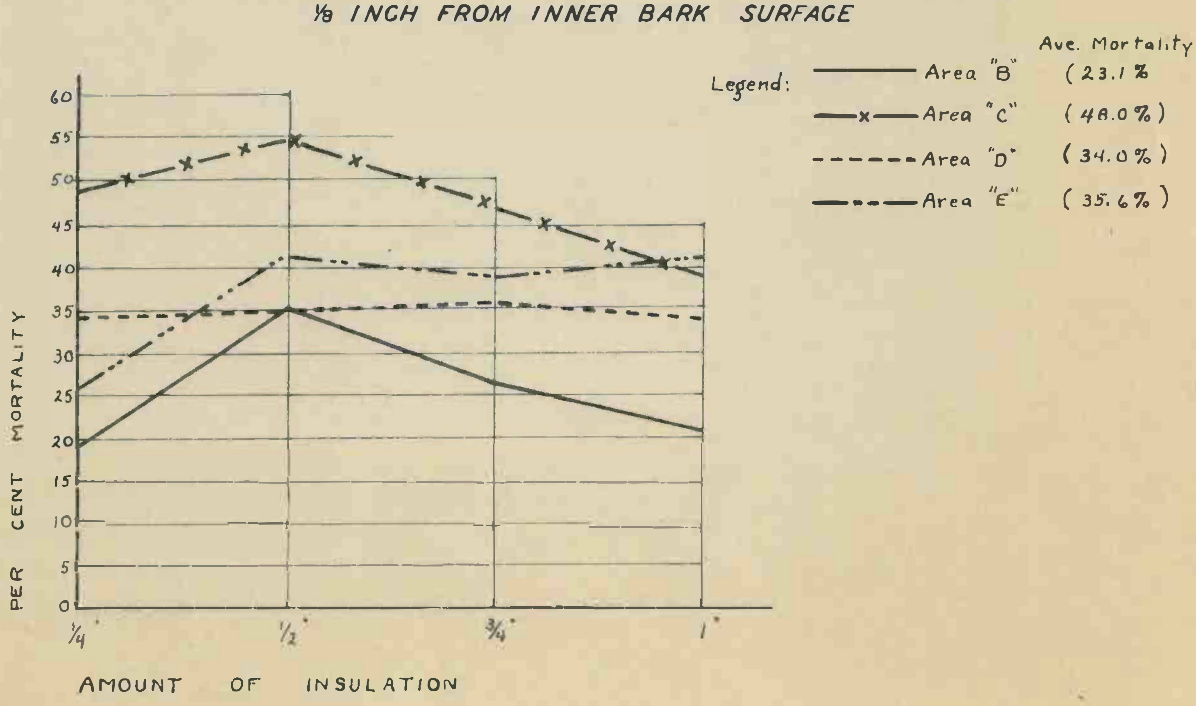


PLATE - 4

RELATIONSHIP BETWEEN MORTALITY OF D. BREVICOMIS AND PROXIMITY TO INNER BARK SURFACE

FIGURE - 12

MORTALITY TO ALL THIRD AND FOURTH INSTAR LARVAE

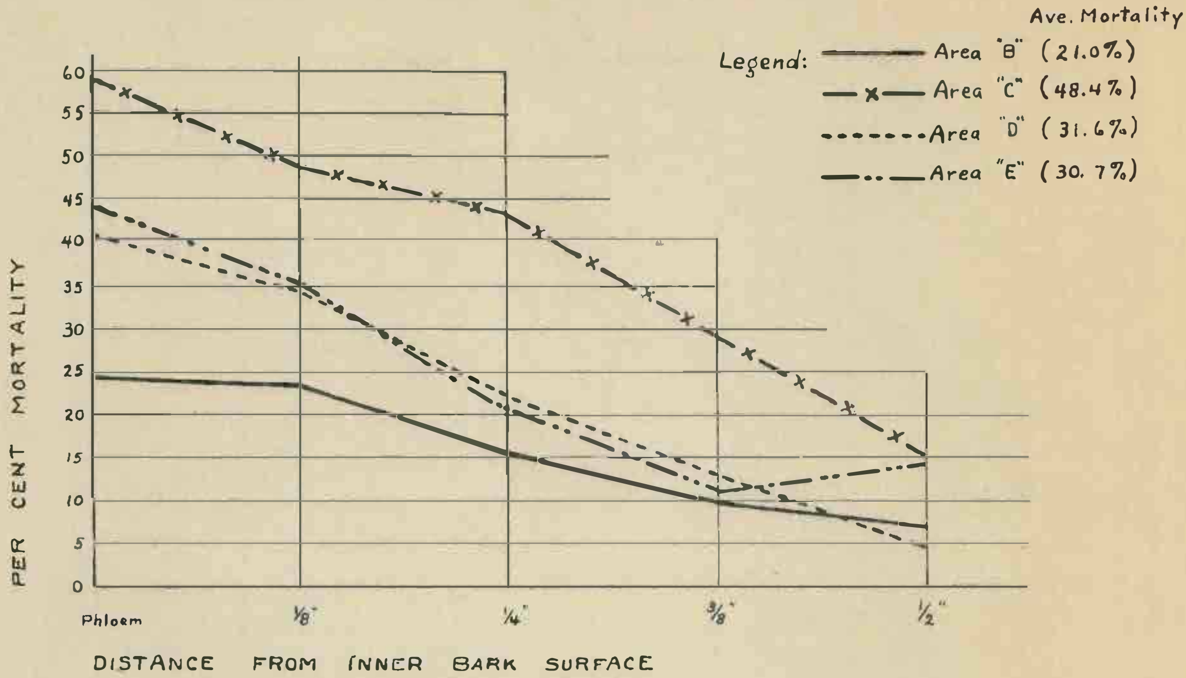


FIGURE - 13

MORTALITY TO THIRD AND FOURTH INSTAR LARVAE WITH 1/2 INCH OF INSULATION

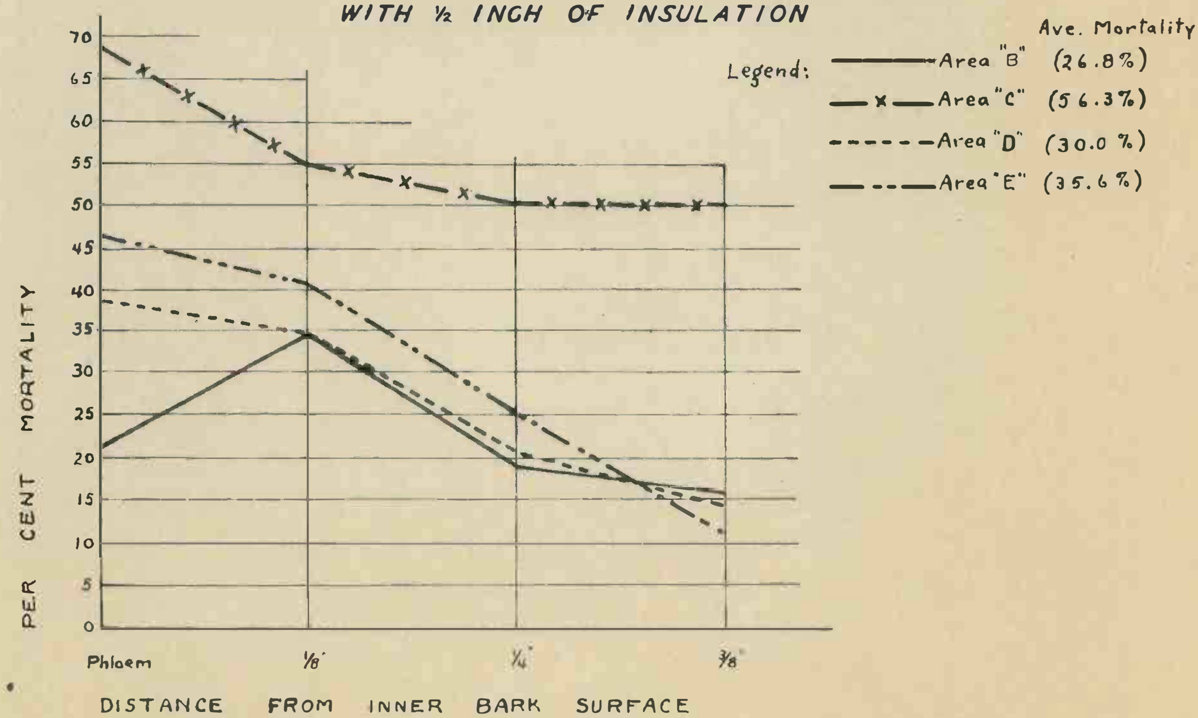
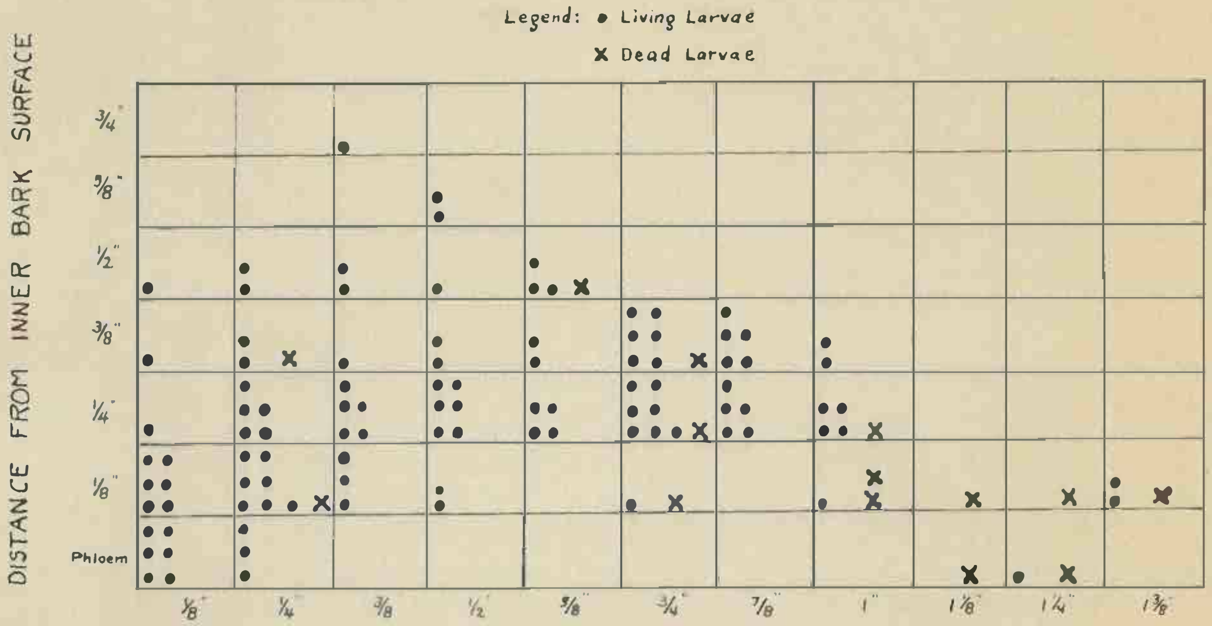


PLATE - 5

DISTRIBUTION OF LARVAE - LIVING AND DEAD - IN TWO SAMPLES FROM AREA "C", SEE TEXT.

FIGURE - 14

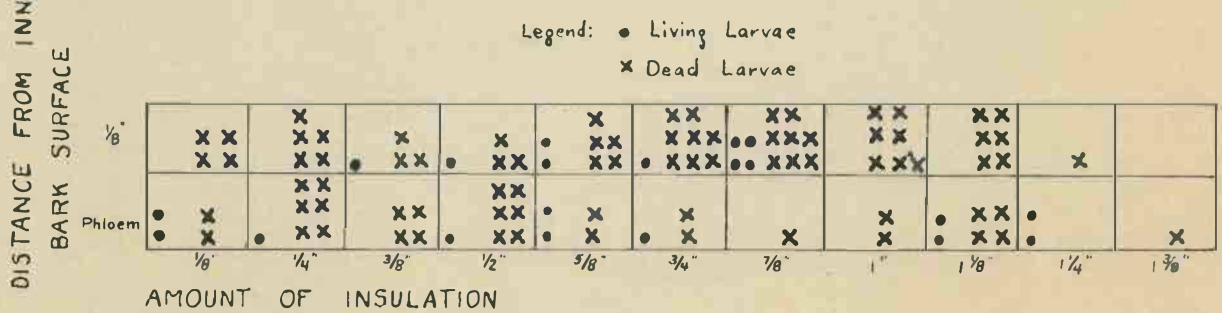
DIAGRAM SHOWING SCATTER DISTRIBUTION OF LARVAE



Note: Bark thickness 1½". Brood nearly all fourth instar larvae. 102 living, 14 dead.

FIGURE - 15

DIAGRAM SHOWING CONCENTRATION OF LARVAE NEAR PHLOEM



Note: Bark thickness 1½". Brood nearly all fourth instar larvae. 20 living, 80 dead

FIGURE - 16

RELATIONSHIP OF MINIMUM AIR TEMPERATURES TO D. BREVICOMIS MORTALITY